Institute of Theoretical and Mathematical Physics

Russian Federal Nuclear Center -

VNIIEF

Monte Carlo Simulation of Joint Transport of Neutrons and Photons

***Zhitnik A.K.,* Artemeva E.V., Bakanov V.V., Donskoy E.N., Zalyalov A.N., Ivanov N.V., Ognev S.P., Ronzhin A.B., Roslov V.I., Semenova T.V.**

RFNC-VNIIEF, 607190, Sarov, Nizhni Novgorod region

The approaches used at VNIIEF to simulate transport of neutrons and photons in standard (with surface description of region interfaces) and grid geometries are considered in the paper. Summary of TDMCC code intended for solving dynamic problems of operation of water reactors is presented

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History

The first Monte Carlo computations at VNIIEF were carried out in 1958.

Program version	Year
C-2	1960
C-20	1962
C-30	1964
C-60	1969
C-90	1988
C-95	**1995**

SOLVABLE PROBLEMS

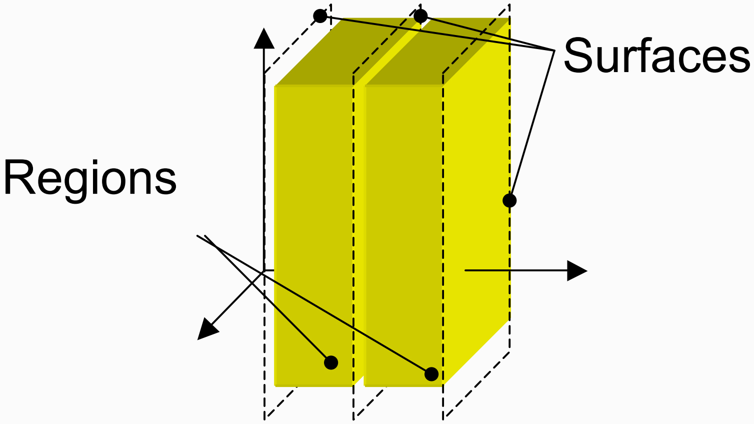
- ✓joint transport of neutrons and photons in 3D systems,
- ✓protection problems,
- ✓calculation of critical parameters,
- ✓nuclear safety problems,
- ✓reactor problems,
- ✓solution of problems in grid geometries.

Geometry

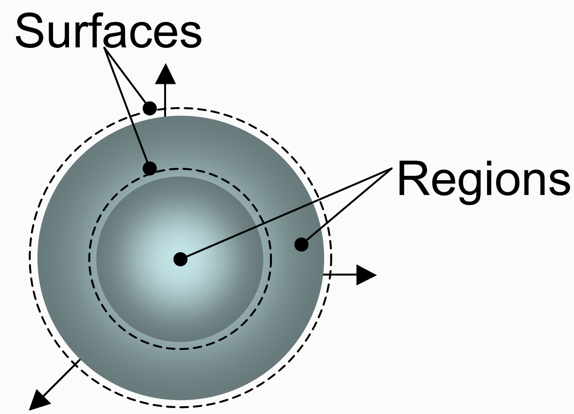
A key entity in specification of geometric data is a geometric **BLOCK**.

BLOCK types:

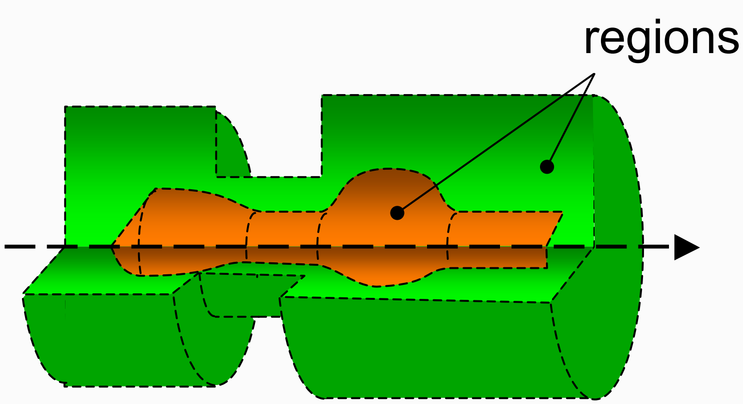
- Plane



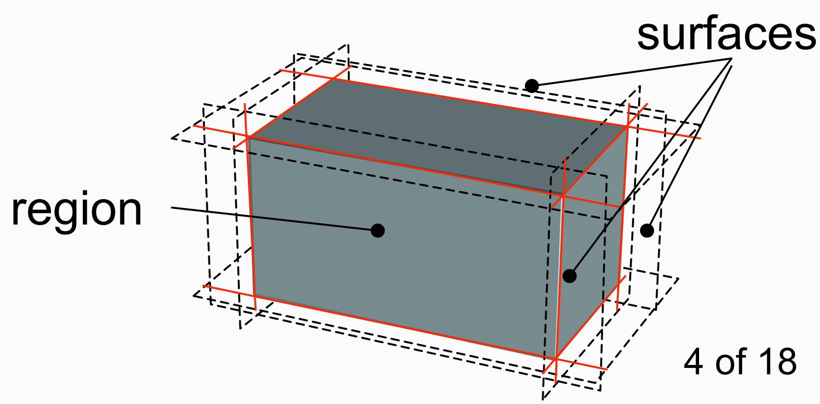
- Spherical



- Axially symmetric



- Three-dimensional



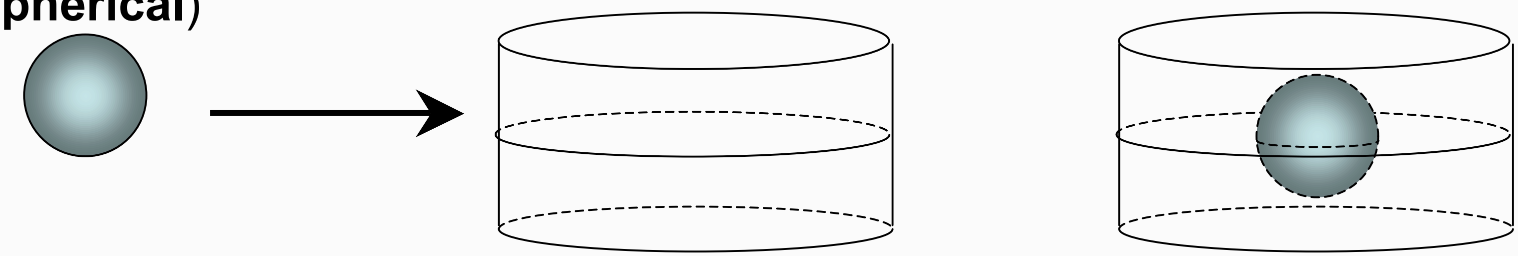
Geometry

The geometry composed of nested blocks looks like a “**matreshka**” (a set of nesting dolls).

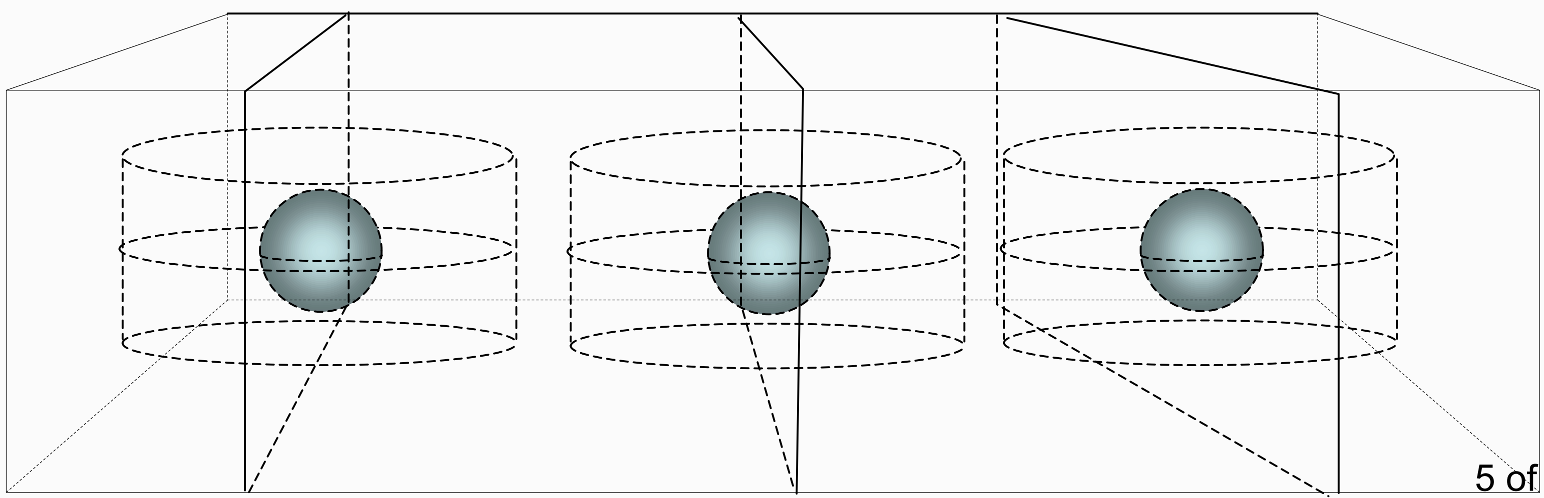
Block 1, 1 region (**spherical**)

Block 2, 2 regions (**axially symmetric**)

Block 1 is nested into **Block 2** one time



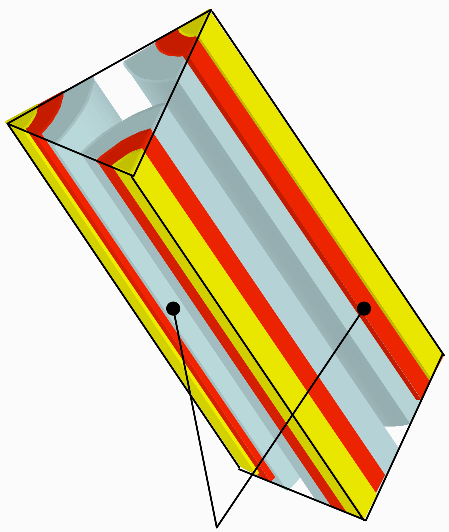
Block 2 (with nested **Block 1**) nested in **Block 3** (3 regions, **three-dimensional**) three times



Geometry

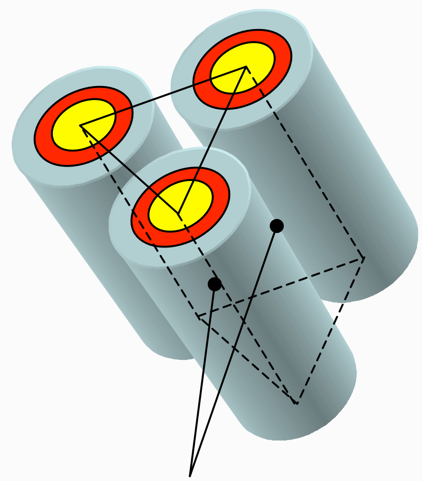
Control Block - This block is superimposed onto the main system and its geometry is built to provide easier specification of the computation tactics and obtainment of results.

Without **control block**



Reflection on surfaces

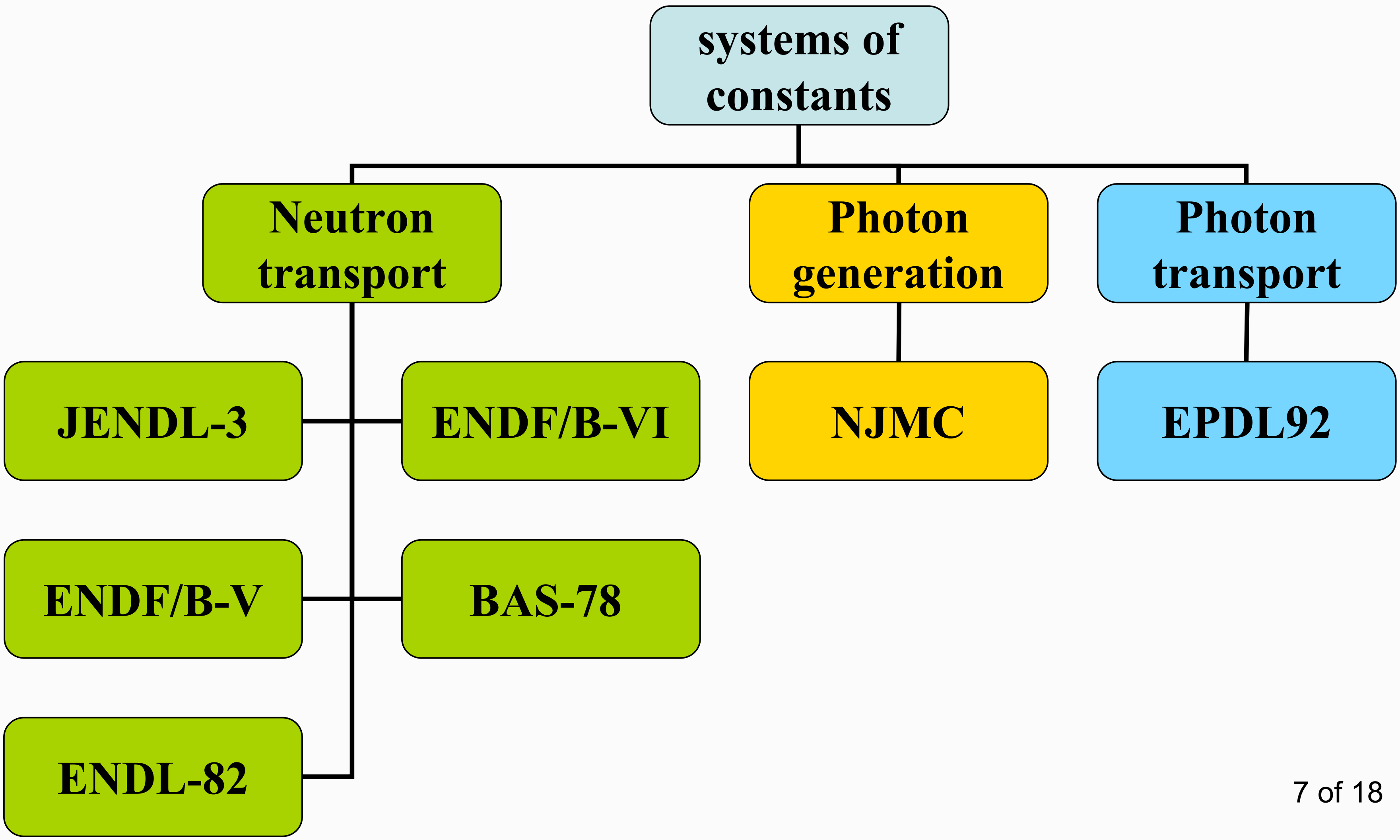
With **control block**



Reflection on surfaces of **control block**

Compositions and constants

The code allows using various systems of constants describing particle/material interactions.



Source

The problem allows specification of a random number of elementary sources, such as a point, a region, a surface. There is a wide range of possibilities to specify the energy-angular distribution.

The distribution in space:

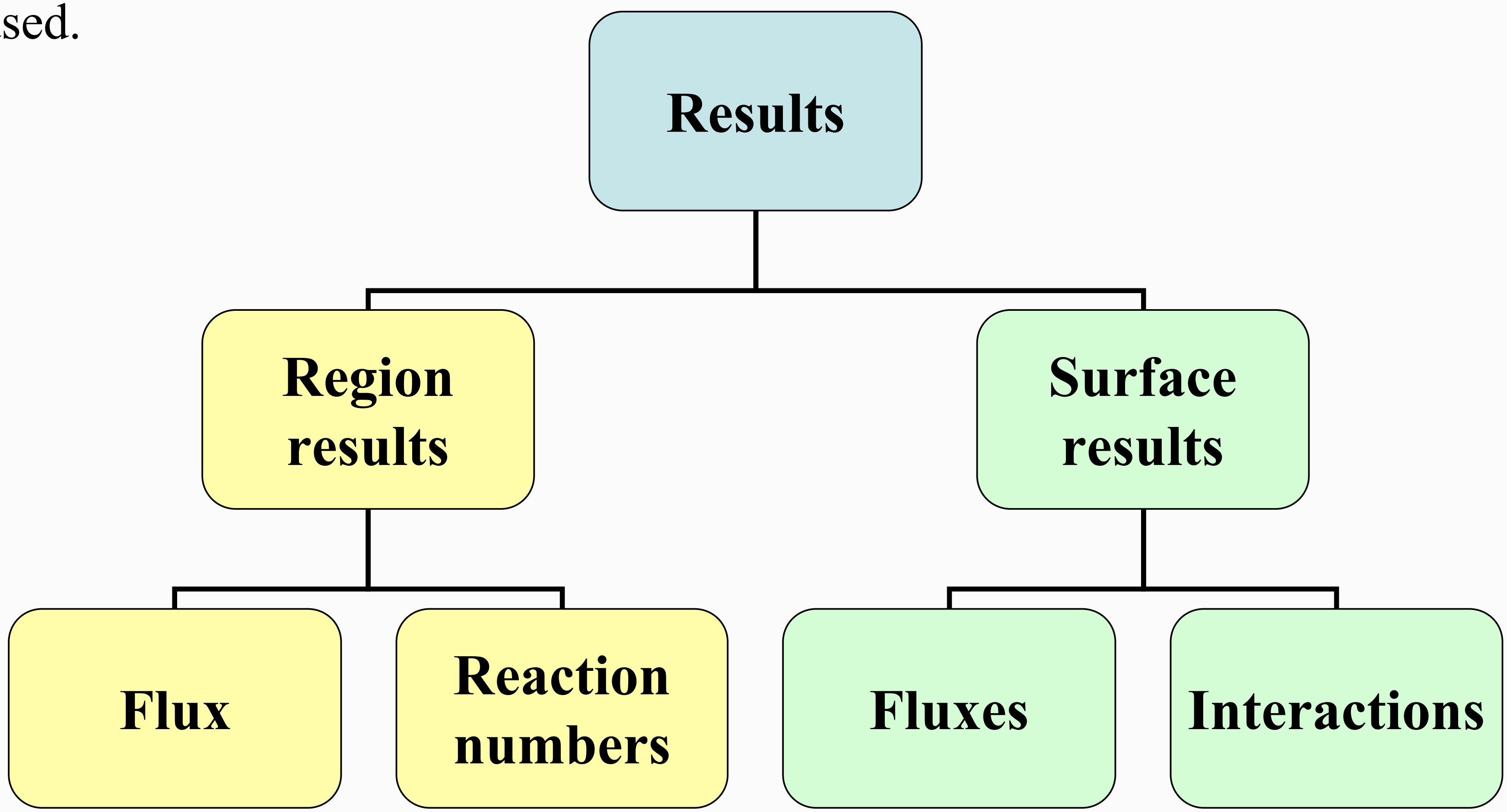
- ***sphere and spherical layers,***
- ***cylinder and cylindrical layers,***
- ***bar,***
- ***point,***
- ***rectangle,***
- ***trapezium,***
- ***a surface of an arbitrary shape,***
- ***system region.***

There is a possibility to specify a **source** as an **ensemble of particles**, i.e. a set of particles with their specified coordinates, directions of flight and energies.

Results

Each result can be multiplied by a function depending on one of the parameters.

Each result can be distributed over an arbitrary set of parameters. To calculate results in a region, collision estimator and track-length estimator are used.



Simulation and Tactics of Computations

Simulation of neutron and photon transport is performed in accordance with the chosen system of constants of interactions between the corresponding particles and material.

The scheme of maximum piecewise-constant cross-sections is used to draw a free range (a stopping range) and select a material, on which collision takes place. Consideration of thermal motion of the medium nuclei is possible either by consideration of chemical bonds (the so-called ***S(α, β model)***), or in free Maxwell gas approximation.

Several methods improving the computation efficiency has been introduced into the code, they are:

- ***Splitting and roulette;***
- ***Two types of surface reflection;***
- ***Weight windows;***
- ***The value of particles in the system regions;***
- ***Exponential transformation;***
- ***The method of trial particles.***

Bremsstrahlung account in photon transport problems

VNIIEF proposed TTBIAS model (Donskoy and Zalyalov, 2003) for bremsstrahlung account in problems of photon transport in “thick” regions. This model supposes local absorption of electrons and positrons and emission of all the generated bremsstrahlung photons. The number of photons, the spectrum-angular and space distributions of energy of bremsstrahlung photons per one event of interaction of the primary photon are calculated beforehand using ELIZA code with taking account of electron and positron transport.The calculated data is placed in tables.

Bremsstrahlung account in photon transport problems

Table 1. Yield of photons forwards.

Source energy, MeV				MCNP	ELIZA
100	0.36748	0.37324	0.00022367	0.655449	0.64093
50	0.14645	0.14831	0.00065050	0.293417	0.28793
20	0.04480	0.04481	0.0034089	0.100999	0.09894
10	0.02564	0.02565	0.011524	0.050011	0.04817

Table 2. Yield of photons backwards.

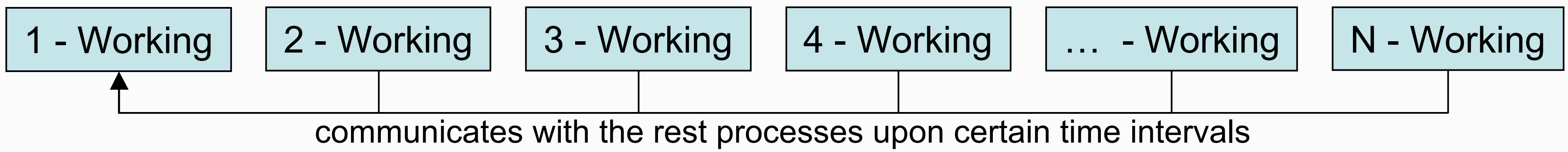
Source energy, MeV		+TTBIAS	+TTBIAS+ annihilation model		MCNP
100	0.73203	0.94920	0.74851	0.27238	0.52134
50	0.55738	0.69756	0.56908	0.24093	0.34223
20	0.37729	0.42794	0.37386	0.18459	0.20653
10	0.22865	0.24796	0.22832	0.13411	0.13866

$\gamma + e^- + e^+$

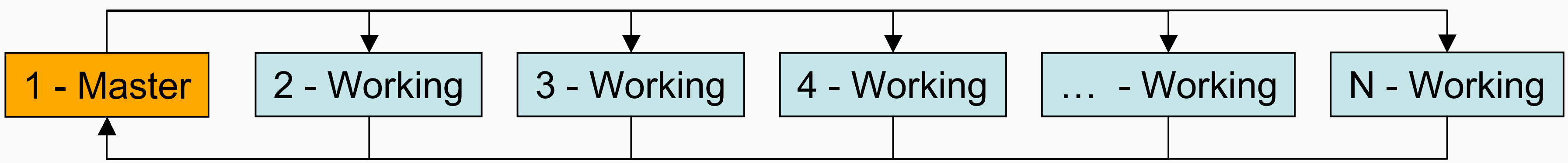
Parallelization algorithms

Parallelizartion algorithms are based on the model with message passing implemented in **MPI library** of interpocessor communications.

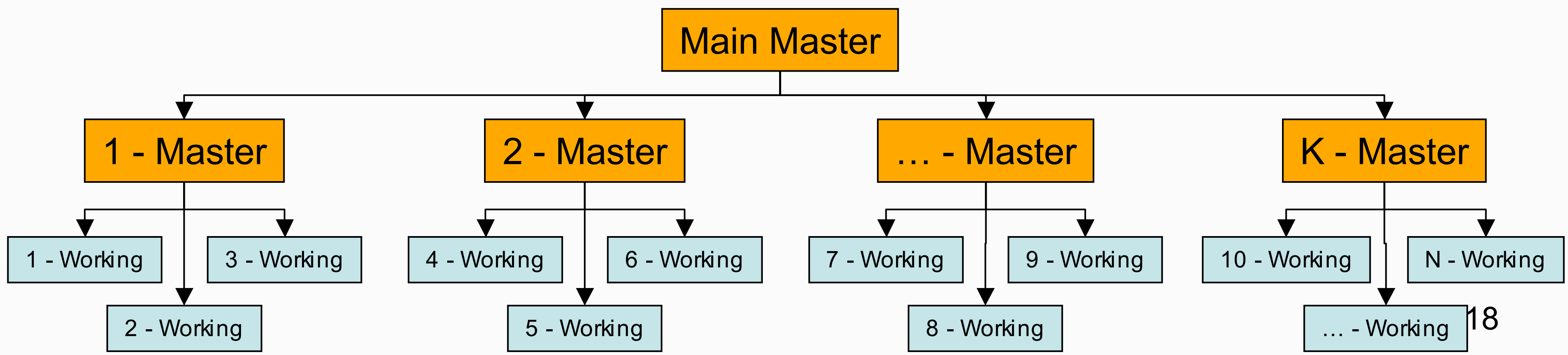
linear transport problems



eigenvalue problems (up to 50 processors)

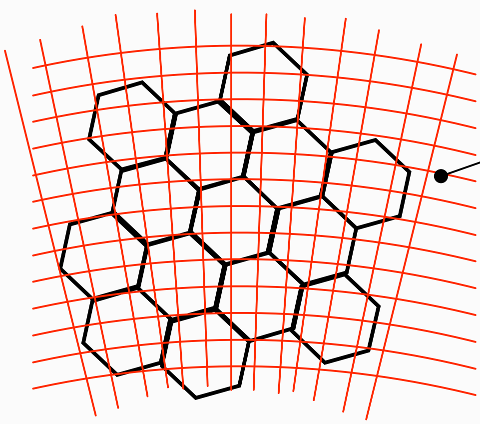


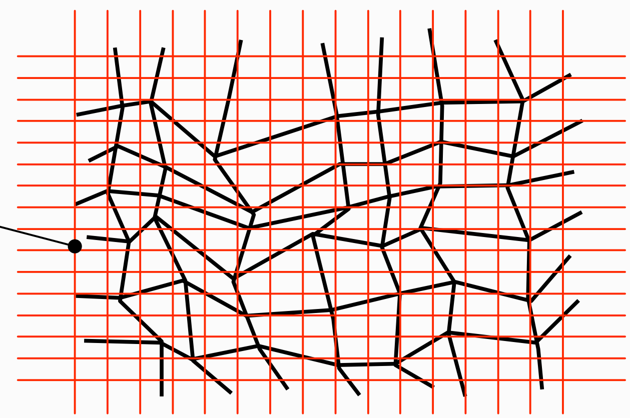
eigenvalue problems on a large number of processors



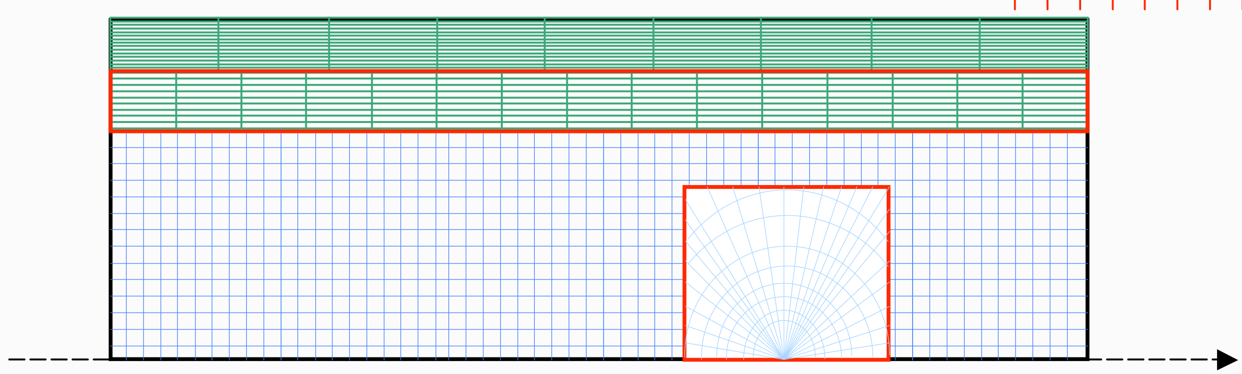
Computations Using Grid Geometry

C-95 code complex has a possibility to use an entity determined by a grid geometry (i.e. a set of cells filled with some material of a certain density) as one of the blocks. It is possible to use either regular grids specified by coordinates of node points, or irregular grids specified by a set of coordinates of vertexes for each grid cell.





using **control block**



TDMCC Code

TDMCC code developed on the base of C-95 code complex is intended for model computations of the dynamics of neutrons in water reactor cores.

1. Its own number is assigned to each fuel rod that characterizes its location in the reactor core.
2. The rods are virtually divided into layers along their height and it is assumed that each layer has its constant composition and uniform distribution of delayed neutrons.
3. To describe data on the compositions of the rods at a current time of reactor operation, a file resultant from computation of the neutron-nuclei kinetics is used.

TDMCC Code

The adopted computational model for the neutron dynamics uses time-step computations. Prompt and delayed neutrons are simulated separately.

The number of simulated particles in ensemble is constant.

Data on neutrons released at time T_0 and survived at time $T = T_0 + \Delta t$ is the input data for simulation of the next batch.

The time of occurrence of delayed neutrons is related to the half-decay periods of their predecessors (fragments of nuclei). With regard to this feature, the delayed neutrons are divided into six groups in the current version of this code.

The method of maximum cross-sections is used to simulate trajectories and thermal motion of medium nuclei is taken into account.

TDMCC Code

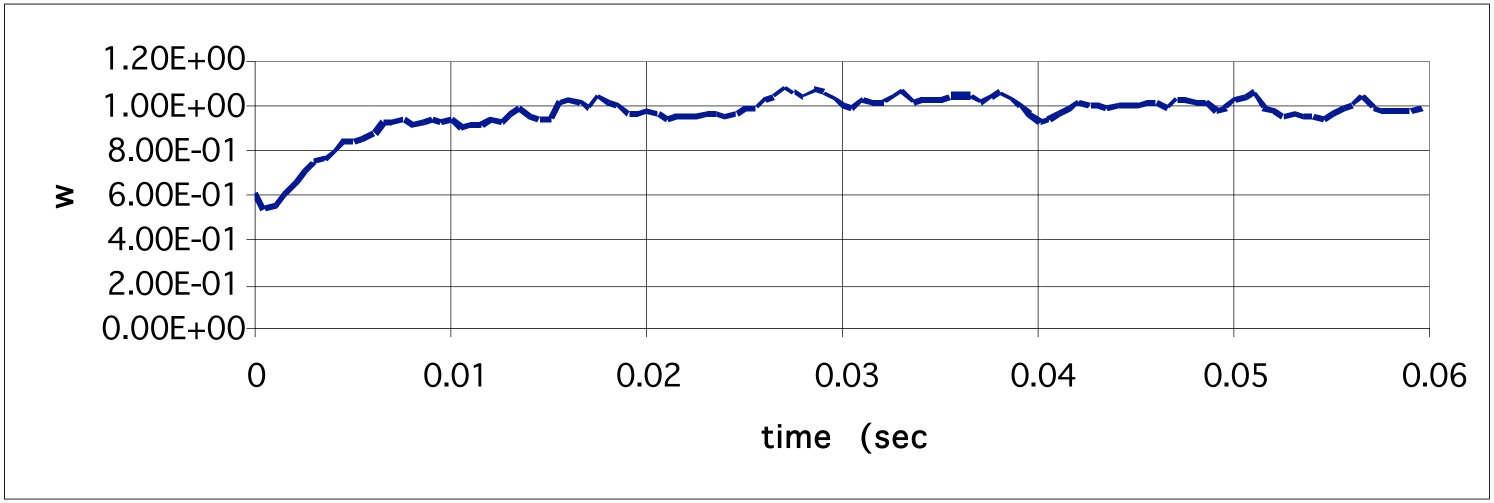


Figure 1. Phase I. Achievement of the steady-state conditions

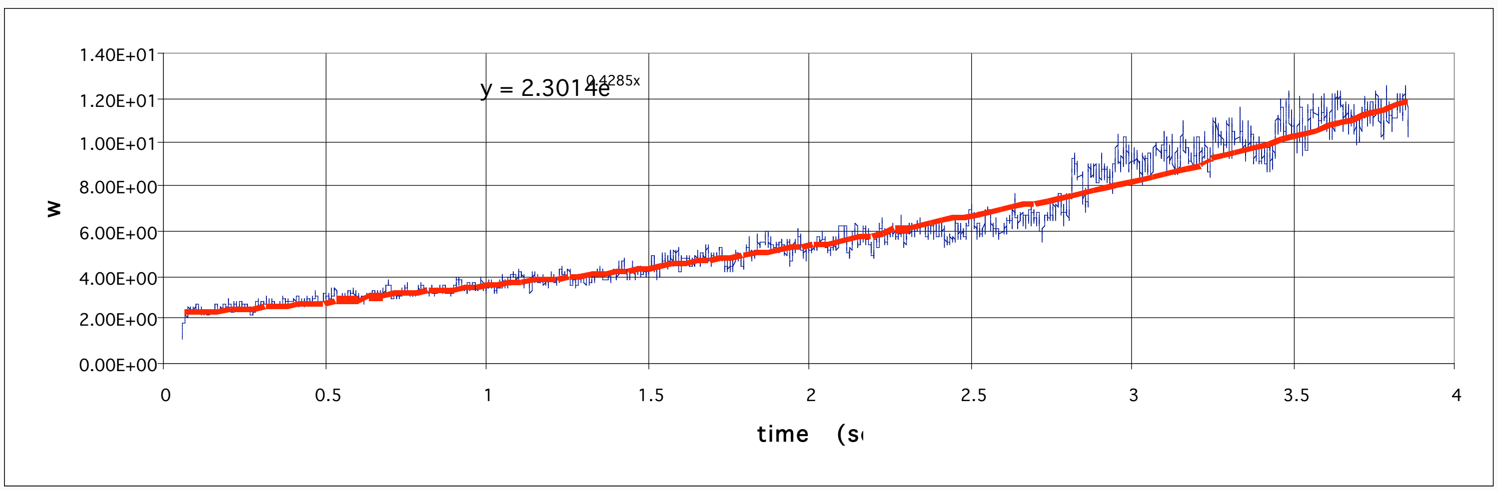


Figure 2. Phase II. The system dynamics after its reactivity has been increased.

TDMCC Code

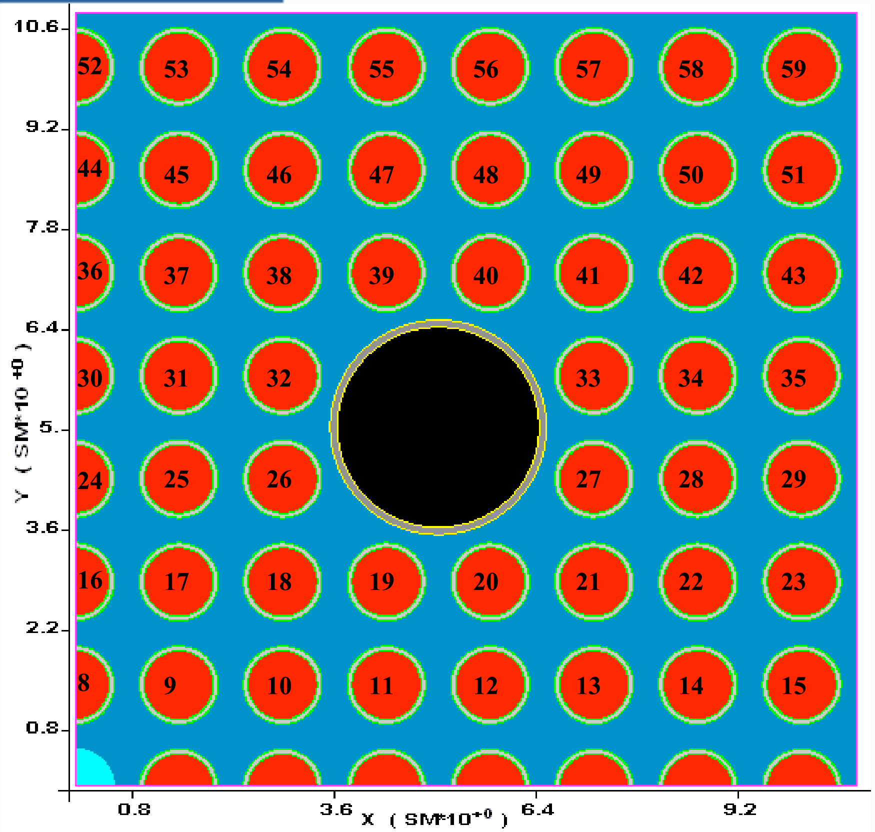


Figure 1. Sample task geometry TDMCC. (Up View)

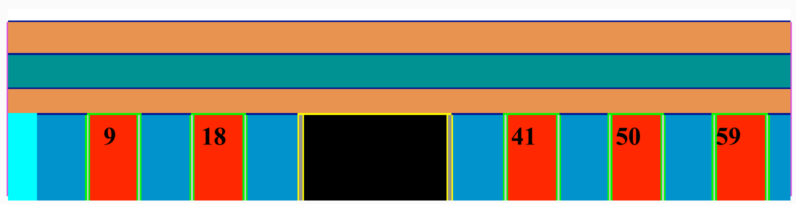


Figure 2. Sample task geometry TDMCC. (Cornerwise section)